Global Precipitation Measurement (GPM) Core Satellite & International Space Station (ISS) Coordination for CubeSat Deployments to Minimize Collision Risk
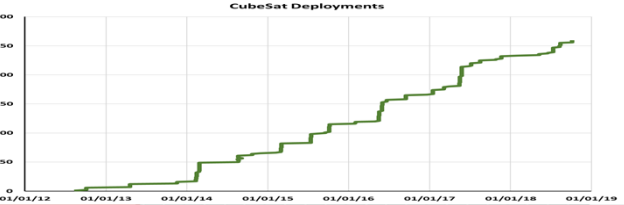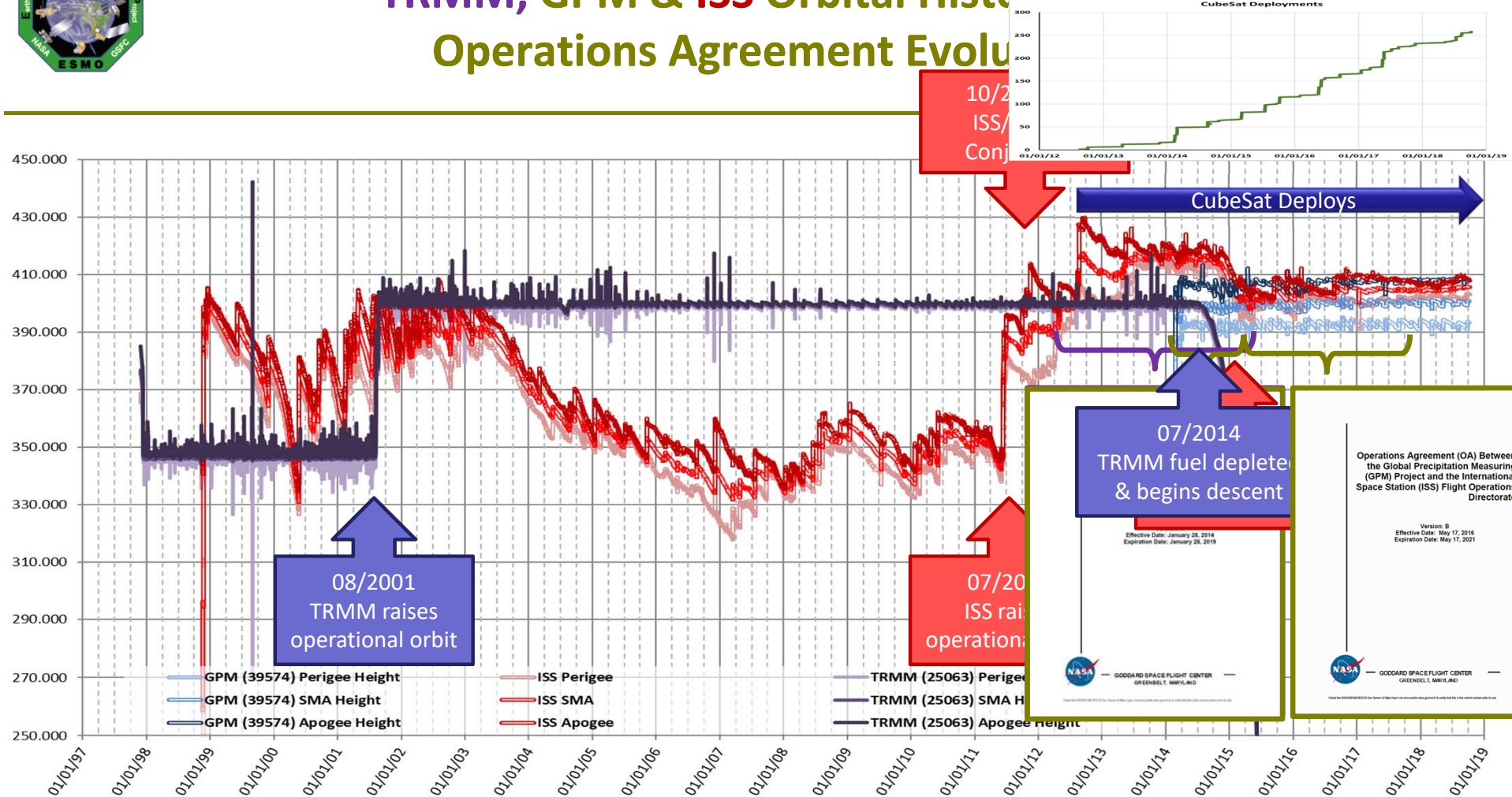
James Pawloski

GPM Mission Manager

NASA Goddard Space Flight Center (NASA/GSFC)

Earth Science Mission Operations (ESMO)

CubeSat Deployments

CubeSat Deploys

10/2...
ISS/...
Conj...

08/2001
TRMM raises
operational orbit

07/20...
ISS rais...
operation...

07/2014
TRMM fuel deplete...
& begins descent

Operations Agreement (OA) Between
the Global Precipitation Measuring
(GPM) Project and the International
Space Station (ISS) Flight Operations
Directorate

Version: B
Effective Date: May 17, 2016
Expiration Date: May 17, 2021

Effective Date: January 28, 2014
Expiration Date: January 28, 2019

GPM (39574) Perigee Height
GPM (39574) SMA Height
GPM (39574) Apogee Height
ISS Perigee
ISS SMA
ISS Apogee
TRMM (25063) Perigee...
TRMM (25063) SMA H...
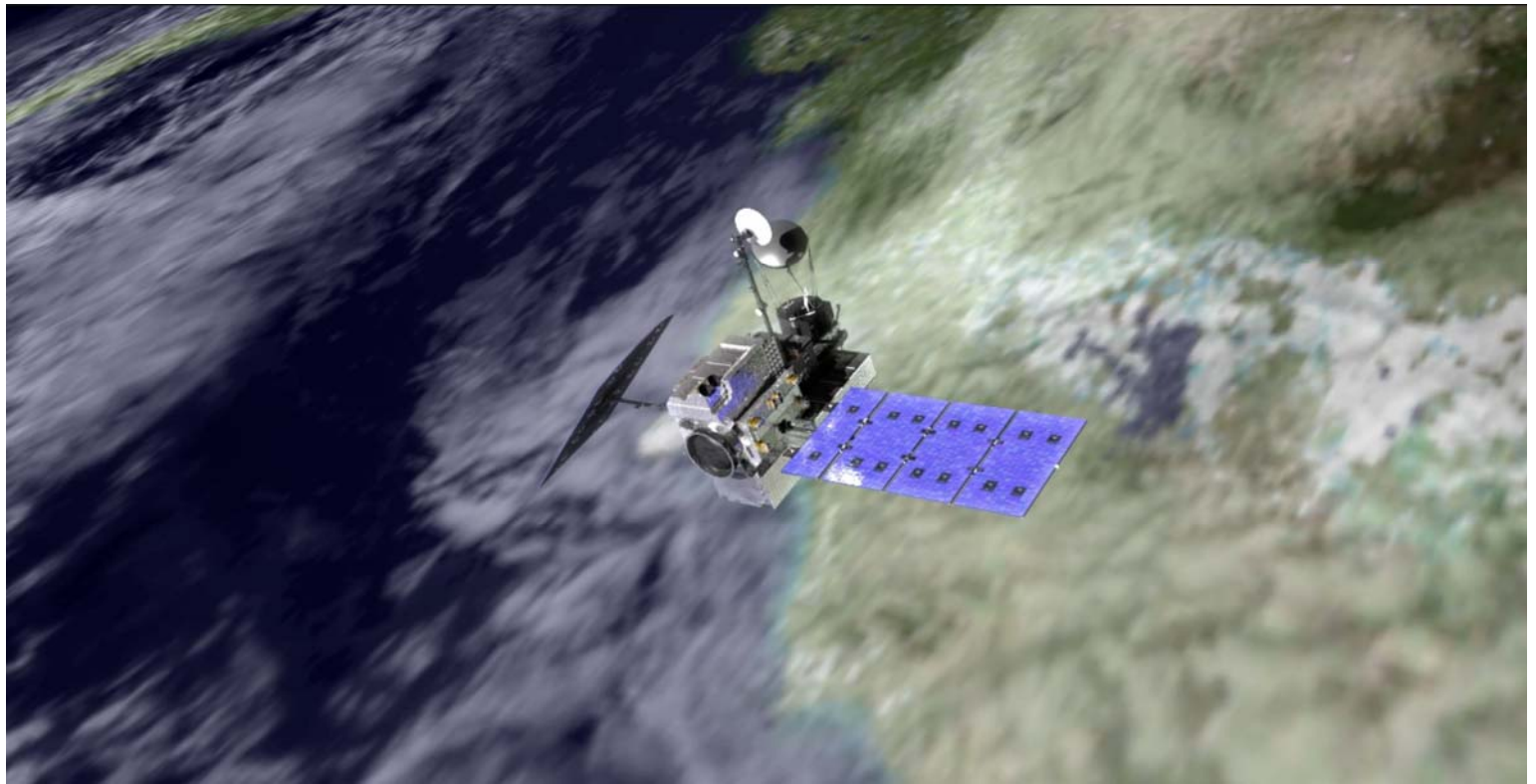TRMM (25063) Apogee Height

GPM Summary

Mass: 3,860kg
Size: 13×5×6.5 [m]
GPM Microwave
Imager
Dual Precipitation
Radar
3 axis stabilized
Earth Pointer

GPM ISS CubeSat Safe Releases

- ISS is currently flying slightly in front of GPM and **as long as ISS is in front of GPM things are fine**.
  - ISS drops off CubeSats and the resulting relative motion is **forward and away from ISS**, thus, GPM will not be immediately at risk until that CubeSat comes all the way around and approached GPM from behind (~50 days) which is more than enough time to track, catalog, perform Conjunction Assessment (CA), plan and prepare a Debris Avoidance Maneuver (DAM).
- *ISS released AESP 14 CubeSat on February 5TH, 2015. The following screen shots show the relative motion of GPM, ISS and AESP 14 in that timeframe*
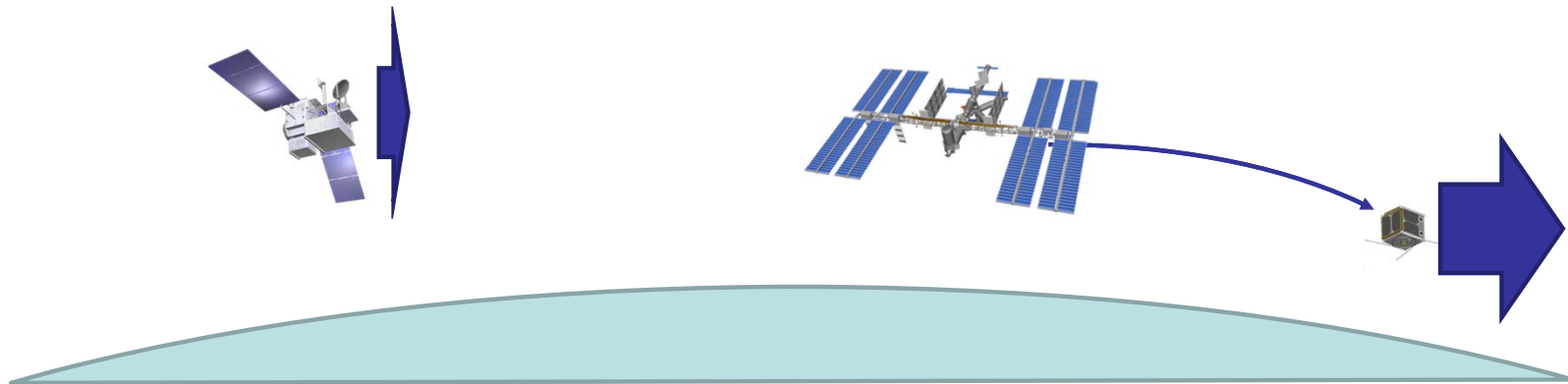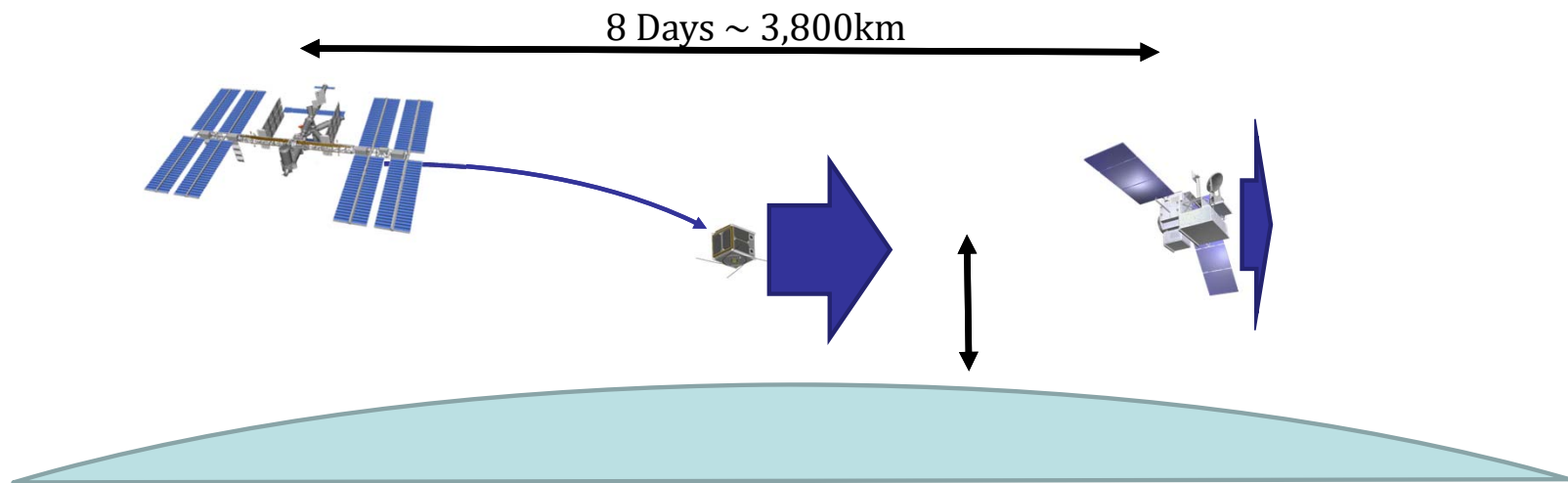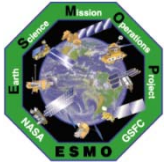
AESP-14 was deployed on 02/05/15
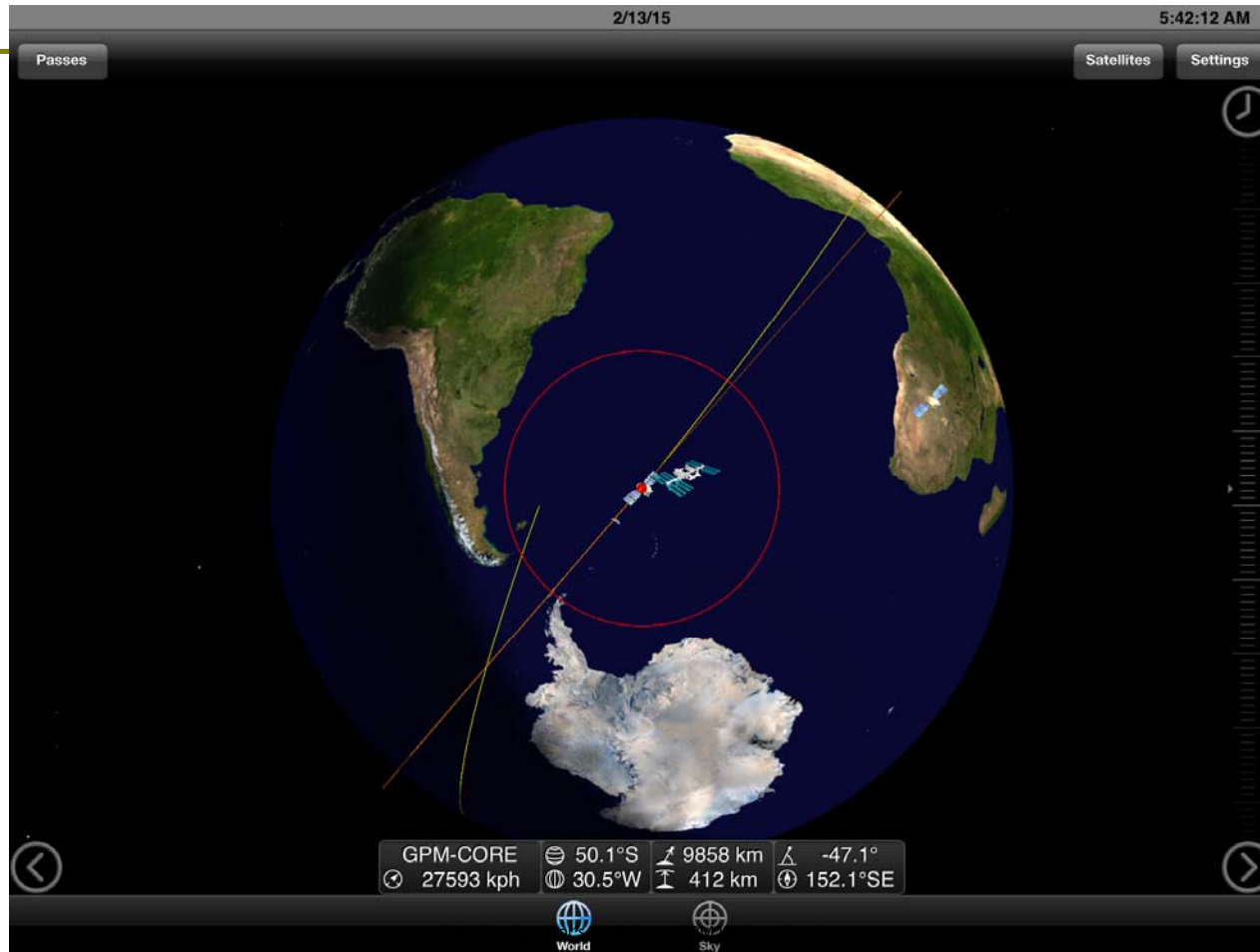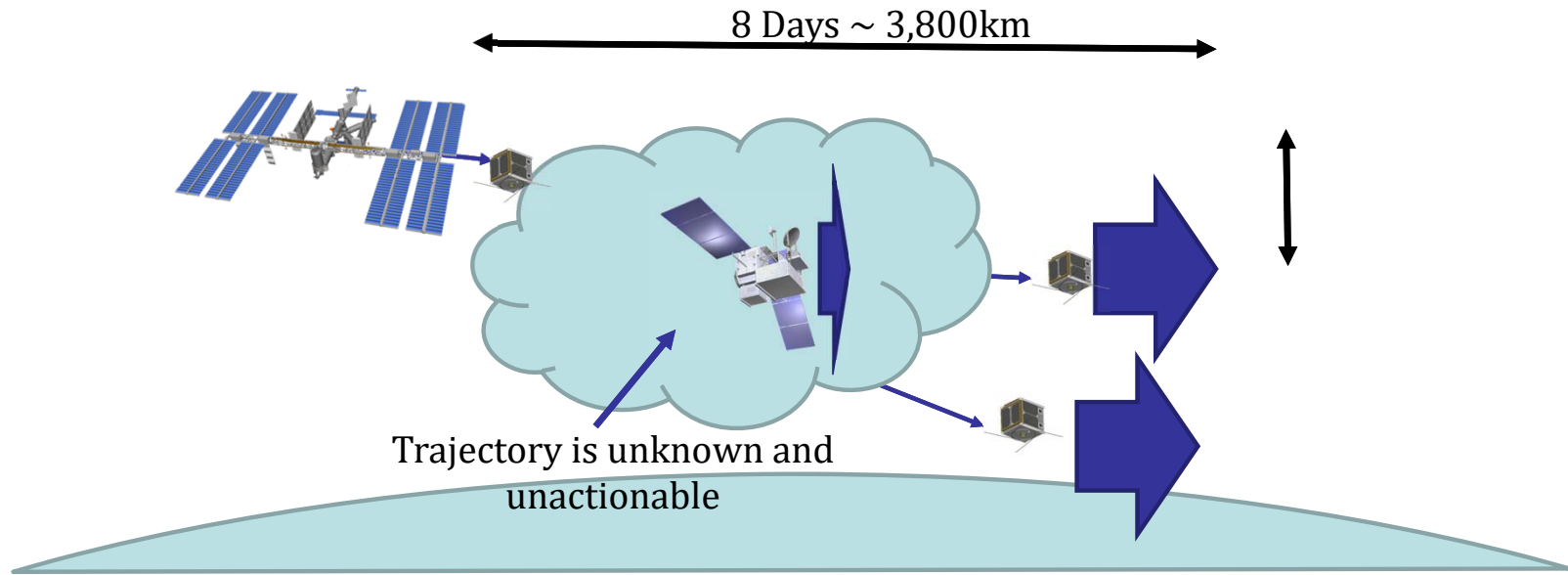
GPM ISS CubeSat Bad Day Scenario

- Both ISS and GPM perform orbit maintenance and have different ballistic coefficients
- So while we are near the same altitude, **if ISS starts to trail GPM** then CubeSat deploy would close in on GPM much faster and possibly have a close approach that we couldn't see or have time to react to.
  - ISS and GPM have both independently used **8 days as the minimum benchmark** needed to perform a DAM.
    - 1-4 days to track & catalog, 2 days to perform CA analysis, 2 days to plan, prepare and execute a burn.

8 Days ~ 3,800km

8 Days ~ 3,800km

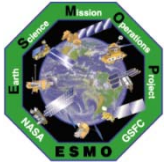Trajectory is unknown and unactionable

GPM/ISS CubeSat Deploy Framework

- GPM and ISS have defined alternative safe strategies to employ that would ensure adequate time between releases and any possible conjunction with GPM.
- The strategy is a three-layer process to focus the attention on the concerning deploys, while maintaining minimal effort for most deployments.

1. **Communications:**
   - The GPM and ISS teams will share ephemeris prediction data to ensure that both teams have situational awareness of orbital and jettison plans.

2. **Deployment Zone:**
   - Define an along-track box relative to ISS that the deployed objects can occupy following the deployment and before the objects are catalogued (~6-8 days).
   - If GPM will not enter this Safe Deployment Zone during the 6-8 days, the deployments are safe and can proceed as planned without any further analysis.

3. **Keep Out Volume:**
   1. Define a Keep-Out Volume around GPM that includes radial as well as cross track
   2. If GPM will be in the Safe Deployment Zone, then perform analysis to determine if the Deployed Object will not enter the Keep-Out Volume during the 6-8 days, the deployments are safe and can proceed as planned without any further analysis.

- Deployments that do not meet either of the above criteria, will be elevated as a collision risk, delayed or waived

The Deployment Zone Visualized

GPM Relative Orbit Phase with ISS
(Mar 04 2015 00:00:00 to Aug 31 2015 00:00:00)
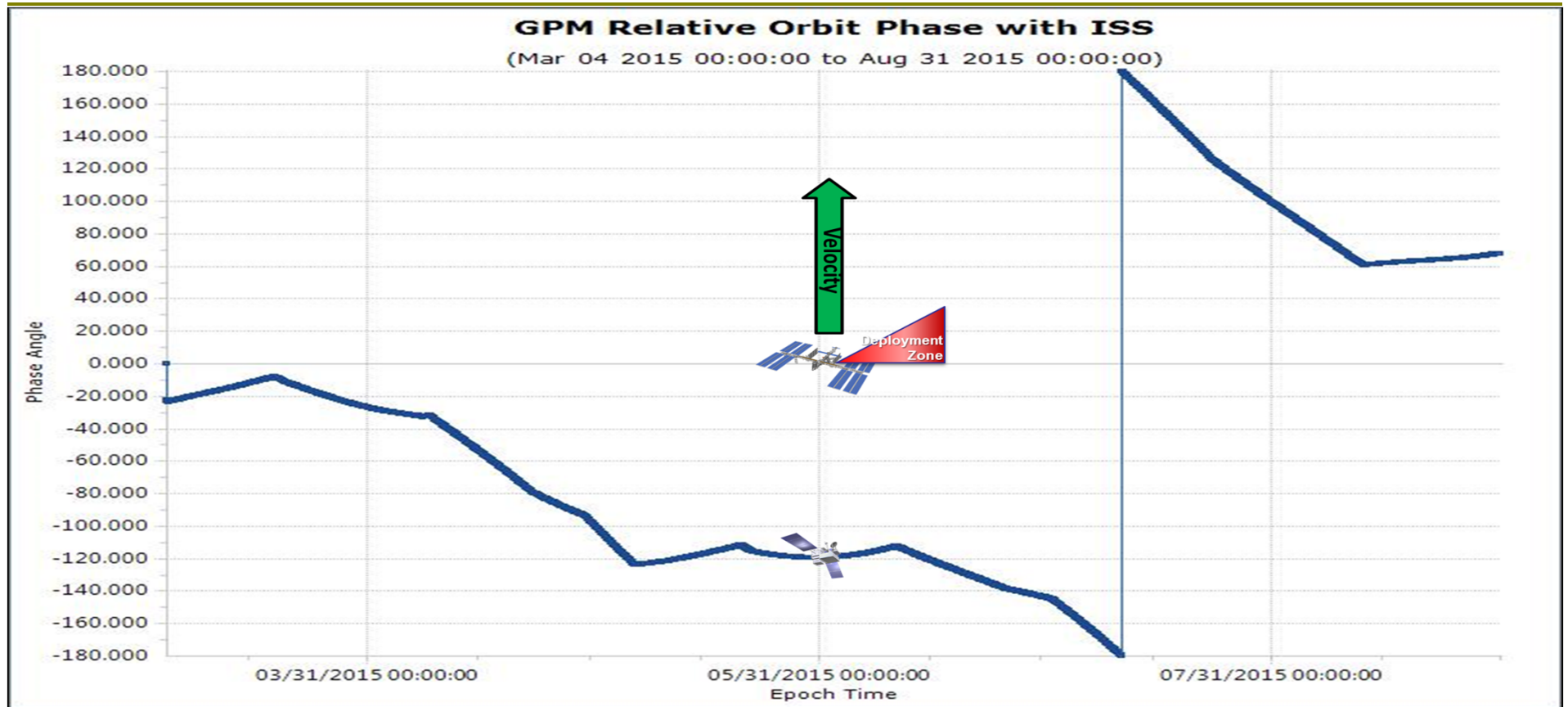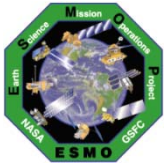
Safe Deployment Process

Agreement Core Principles	
STEP 1:	Enable communications between operations teams for situational awareness
STEP 2:	Share predicted trajectories to allow relative motion & phase analysis
STEP 3:	Reduce the problem to one dimension, along track, to determine if a conjunction is possible. Try to keep GPM out of the Deployment Zone.
STEP	If needed, conduct more sophisticated analysis to determine if a conjunction is possible
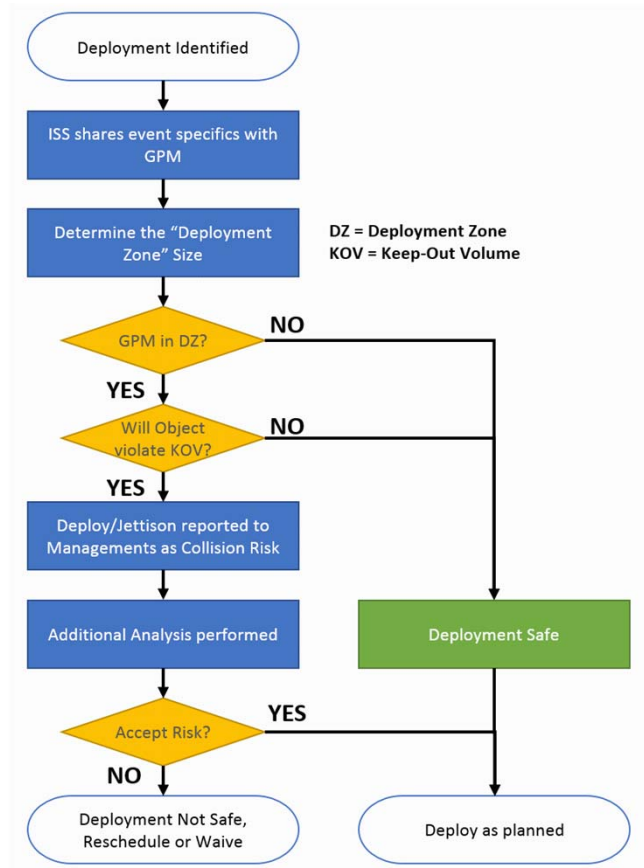
DZ = Deployment Zone
KOV = Keep-Out Volume

GPM/ISS CubeSat Release Agreements

Agreement #15: ISS agrees to alert GPM for planned deployments and jettisons. Alerts shall include the deployment item(s), the planned deployment date and time, the size, mass and expected deployment velocity expected at least a month in advance.

Agreement #16: ISS agrees to alert GPM 24 hours following successful deployments and jettisons. Alerts shall include the deployment item name(s), the date and time of deployment and the Joint Space Operations Center (JSpOC) catalog ID.

Step #1

Agreement #17: ISS/Trajectory Operations and Planning Officer (TOPO) agrees to provide a weekly predicted ephemeris (8-week span) to the GPM Flight Operation Team (FOT) for purposes of predicting GPM/ISS separation distance and Drag Make-Up Maneuver (DMUM) planning and monthly 6-month long term predicted ephemeris.

Agreement #18: GPM agrees to provide ISS/TOPO a weekly predicted ephemeris (30-day span) for purposes of predicting GPM/ISS separation distances.

Step #2

Agreement #19: ISS/TOPO and GPM agree that deployments and jettisons are safe deployments if GPM will be flying outside of the Deployment Zone based on deployed/jettison objects Ballistic Number as defined in or by cased specific analysis at the time of deployment.

Agreement #20: When there is a future projected violation of the Deployment Zone by GPM during an anticipated deployment/jettison, GPM agrees to alter their DMUM schedule, to the greatest operational extent while maintaining all GPM operational requirements related to orbit, in order to avoid or minimize the duration that GPM is resident in the Deployment Zone.

Step #3

Agreement #21: GPM agrees to alert ISS as to the changes made to the DMUM plan that attempts to minimize the time GPM is expected to reside in the Deployment Zone.

Agreement #22: ISS/TOPO agree that in the case of deployment/jettison events that do not meet all criteria in Agreement #19:, the ISS/TOPO group will conduct further nodal analysis of the specific CubeSat/item to detail that the deployment will not pose a collision risk to GPM. The next level nodal analysis will evaluate the relative geometry at the common nodes which represents the only place a collision could actually occur. The relative geometry will be evaluated accounting for GPM and the specific Cubesat uncertainties. The analysis will be shared with GPM for concurrence.

Step #4

Agreement #23: ISS/TOPO agree that for planned deployments that cannot meet Agreement #19: or Agreement #22:, the deployment will be reported to ISS and GPM programs as a collision risk and the deployment/jettison will not occur until the risk can be discussed. TOPO, GPM Flight Dynamics and Conjunction Assessment Risk Analysis (CARA) will support the discussions.
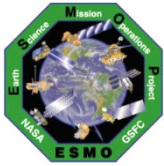
Capturing the Process

- This process is documented an Operations Agreement with ISS and an Appendix

- OA lays out the agreements and framework

- Appendix Z details the Deployment Zone Tables
  - Deployment Zone size (Phase angle and Down Track distance) based on:
  - Deploy Velocity
  - Ballistic Number [BN]
  - # deployed (6 vs 8 days)
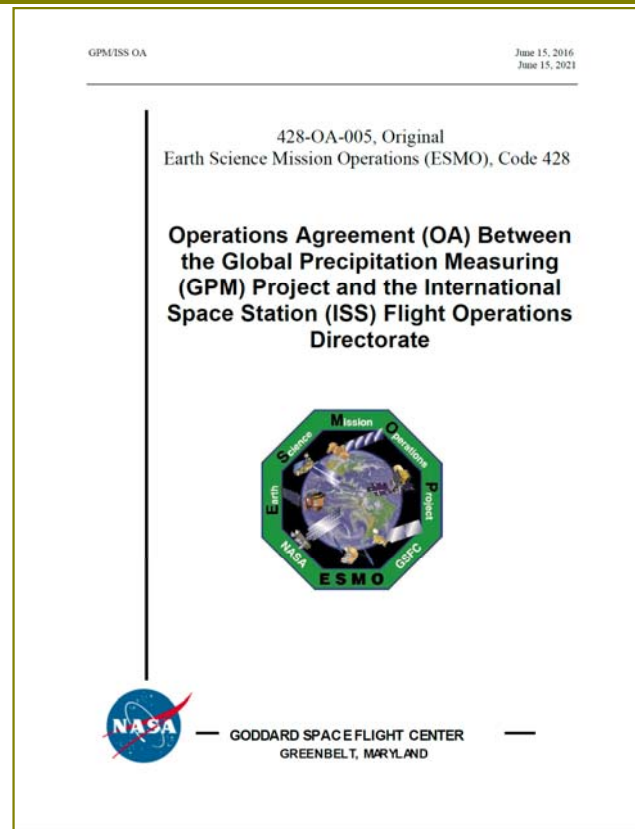
GPM & ISS CubeSat Deploys
2015
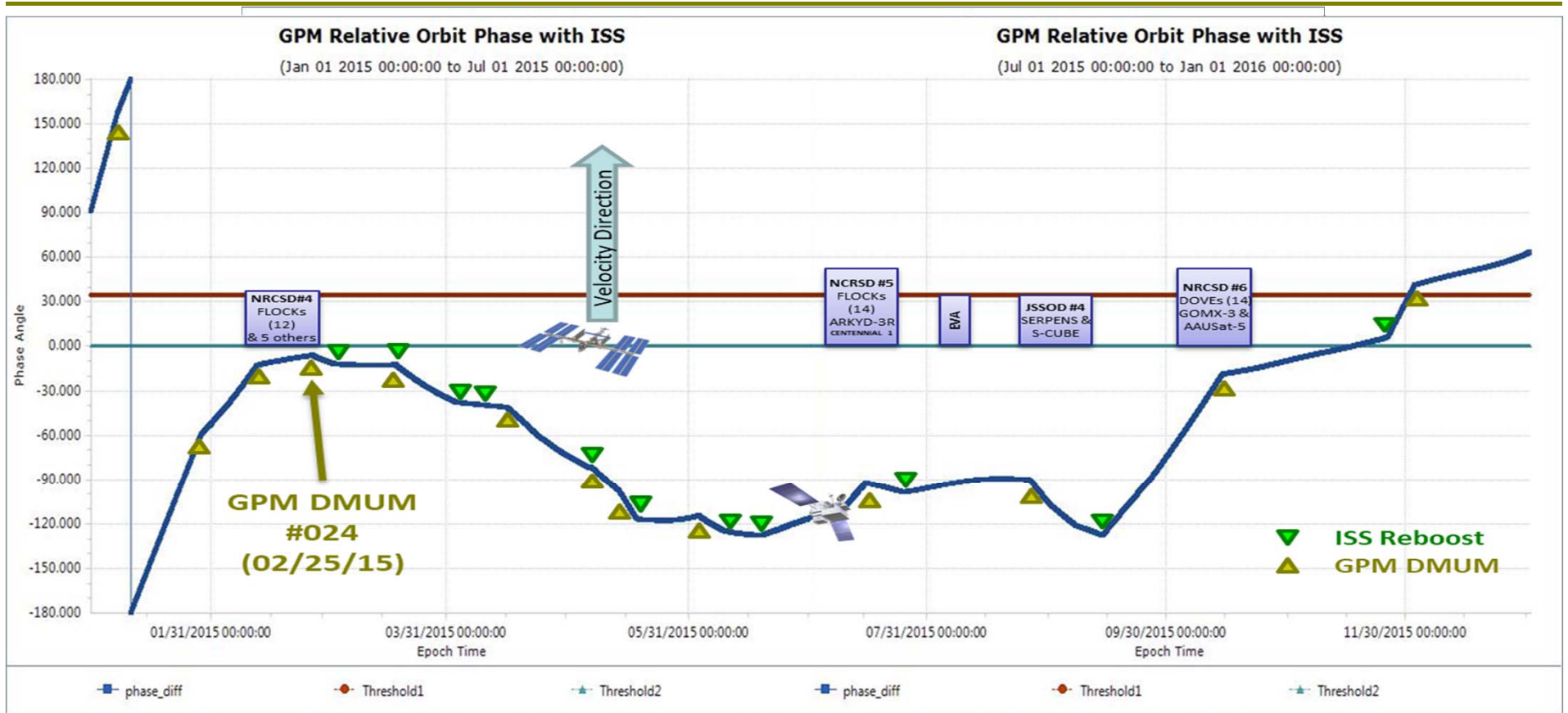
ISS/GPM CubeSats & Distances
2016
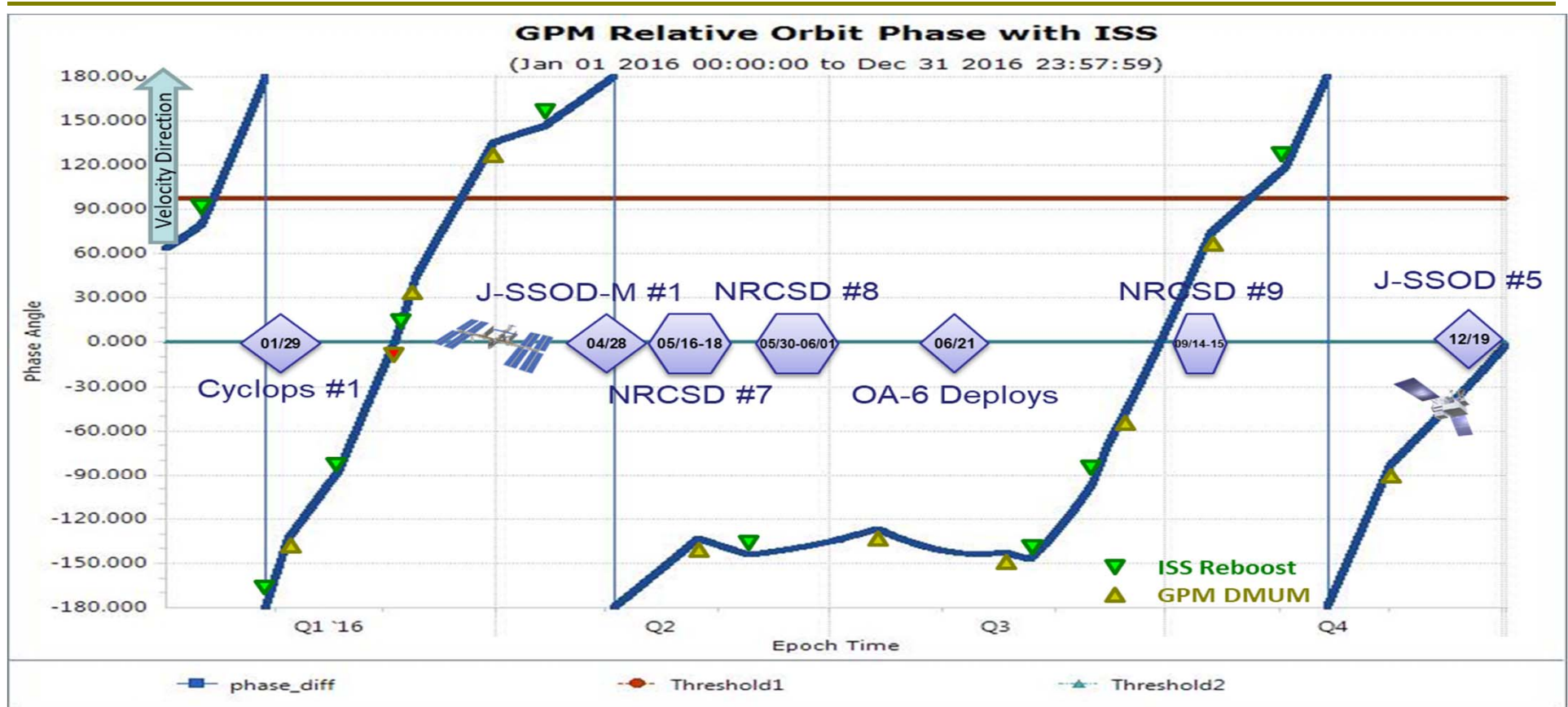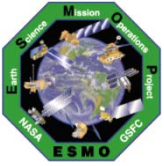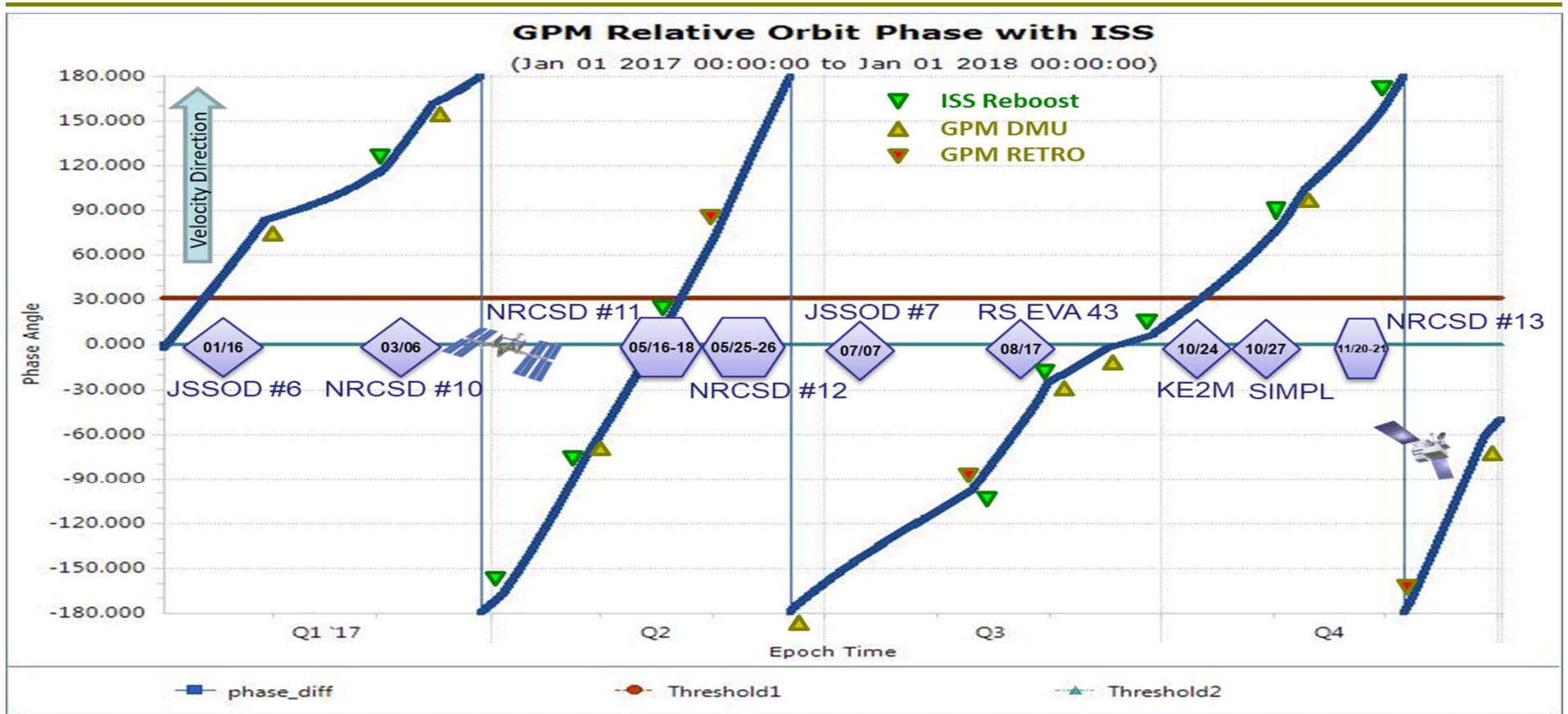
ISS/GPM CubeSats & Distances
2018 (to date)
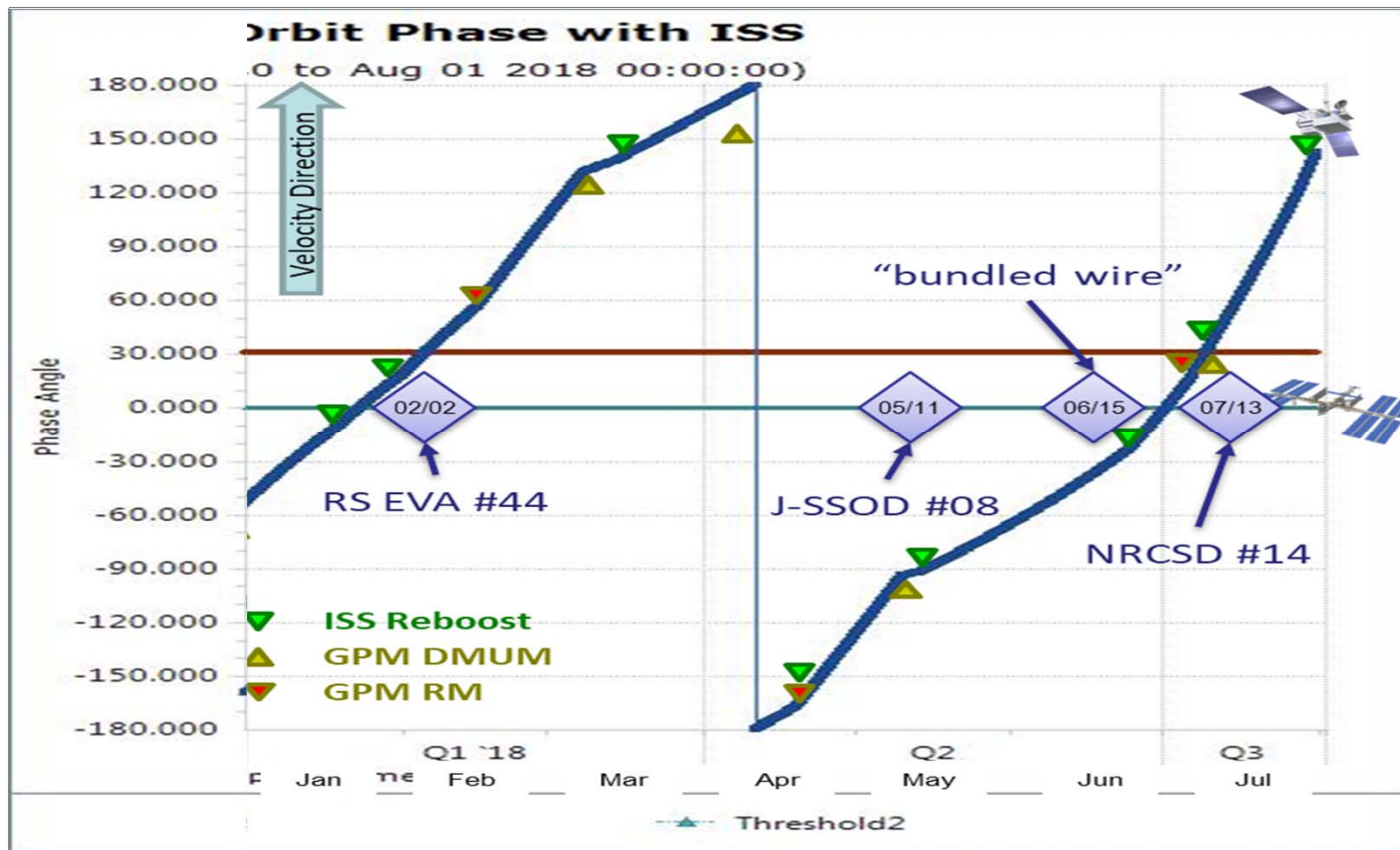
GPM CubeSat History to date

- GPM and ISS/TOPO have successfully coordinated **37** deploy campaigns, releasing **242** cubesats & other objects
- Three (3) released CubeSats required GPM to maneuvers (DAM) to avoid the close approach
  - **10/11/14: DAM #002 (DMUM #017) GPM vs FLOCK 1B-17 @ 10/13/14 08:30:28, Pc 7.60×10⁻⁴ (1 : 1.3k)**
  - **01/28/16: DAM #004 (DMUM #043) GPM vs FLOCK 2EP-17 @ 01/23/17 13:23:28, Pc 9.00×10⁻⁵ (1 : 11k)**
  - **07/09/18: DAM #006 (DMUM #053) GPM vs ISS Debris   @ 07/11/18 15:40:14, Pc 5.24×10⁻⁵ (1 : 19k)**
- ISS successfully deployed 50 CubeSats (and others) safely while in orbit with GPM
  - **Feb 5ᵀᴴ-Mar 3ᴿᴰ, 2015: NRCSD #4   DZ = 3850km**
    - 12 FLOCKs, AESP 14, GEARRS-1, TechEdSAt-4, MicroMas, LambdaSat
- GPM altered their planned burn to avoid passing ISS during deployments **once**
  - GPM moved DMU from 03/04/15 to 02/25/15 to avoid entering the Deployment Zone for NRCSD #14 (50 CubeSats)
  - Effectively flew GPM higher inside the operational envelope to prohibit relative motion toward ISS

Released CubeSats that subsequently reported a non zero Pc w/ GPM

ID	Object	Days	TCA(s)	Deploy Date	Max P_C	ODDS	Action Taken
39532	FLOCK 1-16	3	04/01/2014 09:03:27	02/15/2014	$4.81×10^{-5}$	1 : 21k	CARA Analysis, GPM generated two (2) DAM solutions. Waived off at TCA -7 hours
40140	FLOCK 1B-17	7	10/13/2014 06:30:56	02/25/2014	$1.74×10^{-5}$	1 : 57k	Requested assessment from CARA. Risk abated.
40140	FLOCK 1B-17	4	10/13/2014 08:30:28	02/25/2014	$7.60×10^{-4}$	1 : 1.3k	Requested assessment from CARA. High Interest Briefing held, DAM #002 (DMUM #017) executed on 10/11/14
40738	FLOCK 1E 11	5.0	08/24/2015 04:22:55	07/15/2015	$1.72×10^{-4}$	1 : 6k	None: Object left Reporting Volume after update
40726	FLOCK 1E 7	6.1	08/28/2015 02:28:37	07/14/2015	$3.53×10^{-5}$	1 : 28k	None: Object left Reporting Volume after update
40739	FLOCK 1E 12	6.7	08/29/2015 21:40:56	07/15/2015	$2.18×10^{-4}$	1 : 5k	Requested addition analysis from CARA including 1v1. Pc rolled off.
41576	FLOCK 2EP 10	6.1	07/14/2016 11:11:17	05/31/2016	$2.90×10^{-4}$	1 : 3.45k	None: TCA was prior to planned DMUM #038
41776	FLOCK 2EP 17	6.9	01/23/17 13:23:28	09/15/2016	$9.00×10^{-5}$	1 : 11k	GPM stood up DAM #04, sent to CARA for screening (TCA-2 days) At TCA-24h, Pc subsided. GPM executed DAM #04 on 01/28 for convenience.
41769	FLOCK 2EP 18	6.7	01/31/17 10:07:56	09/15/2016	$7.74×10^{-5}$	1 : 13k	DAM #04 eliminated this close approach as well. No specific mitigation.
42068	LEMUR 2 AUSTINTAICIOUS	6.6	08/01/17 05:51:42	03/06/2017	$4.66×10^{-5}$	1 : 21K	None. Single non-zero Pc reported that did not violate thresholds. Never updated.
42717	SPACECUBE	4.3	08/29/17 14:24:51	05/18/2017	$9.79×10^{-6}$	1 : 102k	None. Pc reported that did not violate GPM's GPM's thresholds. Receded after 3 updates.
42813	ISS Debris (ROSA)	2.2	08/30/17 21:16:58	06/26/2017	$7.69×10^{-6}$	1 : 130K	None. Pc reported that did not violate GPM's thresholds. DMUM #047 on 08/30 @ 14:00 mitigated the conjunction.
42911	Tanyusha 1	5.9	10/18/17 05:09:59	08/17/2017	$3.42×10^{-5}$	1 : 29k	None. Pc rolled off near TCA – 3 days
43020	ASTERIA	6.9	03/28/18 12:37:45	11/21/2017	$5.22×10^{-5}$	1 : 19k	None. Pc rolled of as TCA approached.
43027	OSIRIS-3U	6.1	02/15/18 12:17:38	11/21/2017	$1.81×10^{-5}$	1 : 55k	None. Pc rolled of as TCA approached.
43498	ISS Debris	3.0	07/11/2018 15:40:14	06/15/2018	$5.24×10^{-5}$	1 : 19k	68+ orbit repeating conjucntion. Consulted with SpaceNav. Proposed 2 maneuvers, CARA Screened. GPM Executed DAM #006/DMUM #053 on 07/09/18
43466	UBAKUSAT	6.6	08/08/2018 22:18:37	05/11/2018	$3.92×10^{-5}$	1 : 26k	None. Updates rolled off ~ 3 days prior to TCA & stayed GREEN
43466	UBAKUSAT	6.8	09/27/2018 03:56:30	05/11/2018	$2.71×10^{-7}$	1 : 4M	None. Updates rolled off ~ 5 days prior to TCA & stayed GREEN
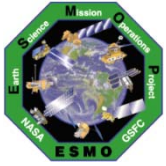
BACKUP CHARTS

GPM/ISS Close Approach Agreements

Agreement #1: GPM agrees to share the GPM Advanced Maneuver Plan when produced, which includes planned propulsive maneuvers, such as DMUMs, with TOPO.

Agreement #2: GPM agrees to share the GPM Maneuver Notifications, when produced, with TOPO.

Agreement #3: TOPO agrees to share planned propulsive activities, such as reboosts or DAMs with the GPM Project as soon as is practicable.

Agreement #4: TOPO agrees to share planned deployment activities, such as CubeSat releases or jettison candidates, with the GPM Project as soon as is practicable.

Agreement #5: GPM agrees to notify TOPO of a predicted close approach with ISS within 24 hours of the initial notification.

Agreement #6: TOPO agrees to notify the GPM Project of a predicted close approach with GPM within 24 hours of the initial notification.

Agreement #7: GPM agrees to consult with TOPO when analyzing and preparing to mitigate a GPM/ISS close approach.

Agreement #8: TOPO agrees to consult with the GPM Project when analyzing and preparing to mitigate a GPM/ISS close approach.

Agreement #9: GPM agrees to share updates regarding a close approach with TOPO.

Agreement #10: TOPO agrees to share updates regarding a close approach with the GPM Project

Agreement #11: GPM agrees to notify TOPO of a waived DAM.

Agreement #12: TOPO agrees to notify the GPM Project of a waived DAM.

Agreement #13: GPM agrees to provide TOPO a DAM Results Summary.

Agreement #14: TOPO agrees to provide the GPM Project a DAM Results Summary.

GPM/ISS CubeSat Release Agreements

Agreement #15: ISS agrees to alert GPM for planned deployments and jettisons. Alerts shall include the deployment item(s), the planned deployment date and time, the size, mass and expected deployment velocity expected at least a month in advance.

Agreement #16: ISS agrees to alert GPM 24 hours following successful deployments and jettisons. Alerts shall include the deployment item name(s), the date and time of deployment and the JSpOC catalog ID.

Agreement #17: ISS/TOPO agrees to provide a weekly predicted ephemeris (8-week span) to the GPM FOT for purposes of predicting GPM/ISS separation distance and Drag Make-Up Maneuver (DMUM) planning and monthly 6-month long term predicted ephemeris.

Agreement #18: GPM agrees to provide ISS/TOPO a weekly predicted ephemeris (30-day span) for purposes of predicting GPM/ISS separation distances.

Agreement #19: ISS/TOPO and GPM agree that deployments and jettisons are safe deployments if GPM will be flying outside of the Deployment Zone based on deployed/jettison objects Ballistic Number as defined in or by cased specific analysis at the time of deployment.

Agreement #20: When there is a future projected violation of the Deployment Zone by GPM during an anticipated deployment/jettison, GPM agrees to alter their DMUM schedule, to the greatest operational extent while maintaining all GPM operational requirements related to orbit, in order to avoid or minimize the duration that GPM is resident in the Deployment Zone.

Agreement #21: GPM agrees to alert ISS as to the changes made to the DMUM plan that attempts to minimize the time GPM is expected to reside in the Deployment Zone.

Agreement #22: ISS/TOPO agree that in the case of deployment/jettison events that do not meet all criteria in Agreement #19:, the ISS/TOPO group will conduct further nodal analysis of the specific CubeSat/item to detail that the deployment will not pose a collision risk to GPM. The next level nodal analysis will evaluate the relative geometry at the common nodes which represents the only place a collision could actually occur. The relative geometry will be evaluated accounting for GPM and the specific Cubesat uncertainties. The analysis will be shared with GPM for concurrence.

Agreement #23: ISS/TOPO agree that for planned deployments that cannot meet Agreement #19: or Agreement #22:, the deployment will be reported to ISS and GPM programs as a collision risk and the deployment/jettison will not occur until the risk can be discussed. TOPO, GPM Flight Dynamics and CARA will support the discussions.

GPM Conjunction Assessment

- GPM performs orbit determination onboard the spacecraft using GPS measurements from the GSFC-built Navigator receiver.
- Every eight hours, Flight Dynamics System (FDS) uses the GPS data and FreeFlyer software for generation of:
  - Predictive and definitive ephemeris products by FDS in the MOC.
  - Covariance Generation
  - Maneuver planning
  - Space Network, Ground Network communications products
  - Conjunction Assessment products
- GPM's orbit has high drag and has a large effect on conjunction assessment (CA) predictions.
- As a result, GPM has adopted a 72 hour (3-day) CA reporting window.
  - CARA monitors conjunctions prior to the 3 days but will only include in reports if less than 3 days from Time of Closest Approach (TCA).
- GPM's CA activities pose a direct threat to the safety of the ISS and therefore, GPM has adopted the same CA thresholds as ISS to mimic their risk posture.
- All ephemerides are screened out and monitored by CARA beginning at 7 days, but conjunctions will only be included in the reports beginning at TCA-3 days.

GPM DAM Process Flow

- **Identification**
  - Reports every 8 hours alerts GPM of the presence of a High Interest Event (HIE).

- **Planning**
  - Include Maneuver Trade Space (MTS) plots for mitigation
  - Mission Ops selects options
  - DAM ephemeris are generated
    - Posigrade or retrograde
  - Delivered to CARA for screening
  - Results are analyzed

- **Execution**
  - FOT generates all burn products.
  - Execution is at the direction of the GPM Mission Director

DAM Process Flow

Identification
TCA < 3 days
Pc > 1.0E-05

HIE Identified → Generate Text Message Alert → TCA < 8H & BLACK? (Y → Go to EDAM) (N) → Determine Mitigation Approach (CA Type) → Assess/Modify Tasking Level

Summary Report

Planning
TCA < 1-3 days

Plan Resources → Generate Burn Solutions & CA Type w/ each update (Ideal, DMUM, Retro) → Solution update significant? (N → Go to CAM) (Y) → Generate Ephems → Send to JSpOC for Screening

Post Screening Results to SpaceTrack → Review Screening Results → Post-maneuver concerns? (Y) (N) → Get Maneuver Contacts → Inform Instruments / Science / PPS

HIE Report

Execution
TCA < 1 day

Hold CAM • Finalize Burn Time → Burn? (Y → Finalize Burn Size → Execute Maneuver → Inform Science & Neighbors) (N → Waive-Off → Deliver/Upload No Burn Products → Inform Science & Neighbors)

HIE Report

Legend:
- FOT
- FDS
- CARA
- JSpOC

GPM EDAM Process Flow

- **Identification**
  - TCA < 12 hours from initial ID

- **Planning**
  - Maneuver Trade Space
  - EDAM is set 15^S duration
    - Posigrade (DMUM) or Retrograde
  - Only criteria for waive off is ISS post EDAM conjunction
    - FDS & TOPO can perform Close approach analysis
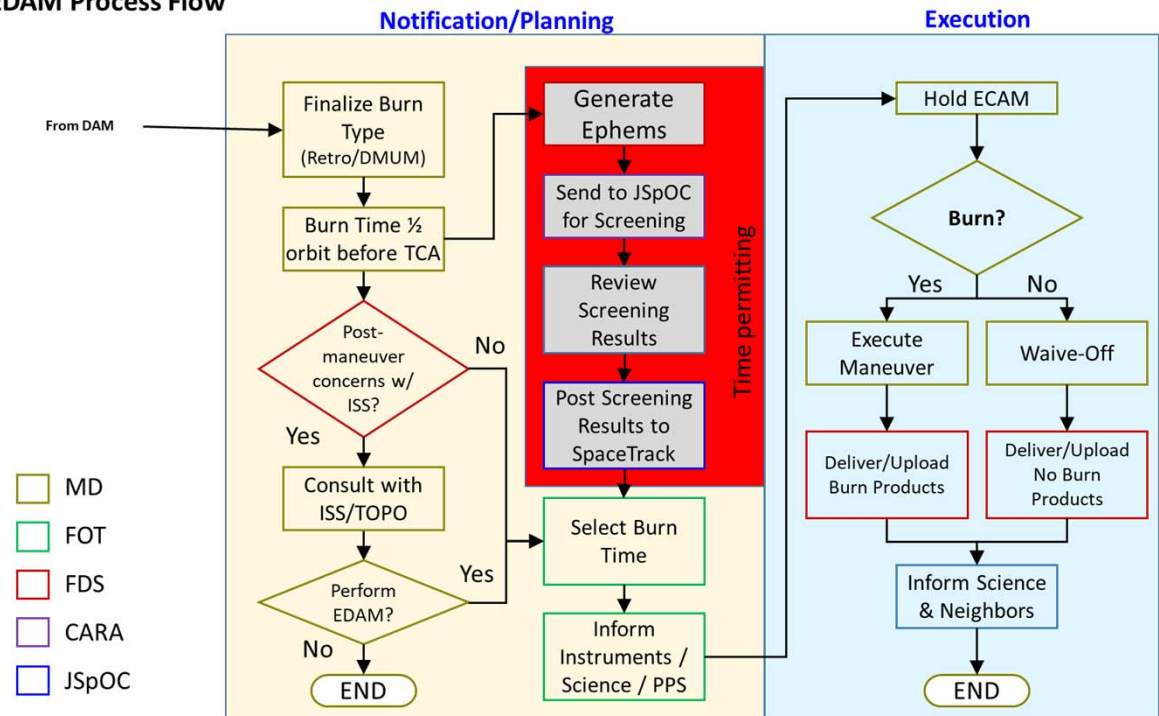 - All other activities are optional

- **Execution**
  - FOT/FDS holds ECAM
  - Execution within 30 minutes of burn at the direction of the GPM Mission Director

EDAM Process Flow

Notification/Planning | Execution

From DAM → Finalize Burn Type (Retro/DMUM) → Burn Time ½ orbit before TCA → Post-maneuver concerns w/ ISS? → No → ... Yes → Consult with ISS/TOPO → Perform EDAM? → No → END / Yes → Select Burn Time → Inform Instruments / Science / PPS

Generate Ephems → Send to JSpOC for Screening → Review Screening Results → Post Screening Results to SpaceTrack (Time permitting)

Hold ECAM → Burn? → Yes → Execute Maneuver → Deliver/Upload Burn Products / No → Waive-Off → Deliver/Upload No Burn Products → Inform Science & Neighbors → END

Legend:
- MD
- FOT
- FDS
- CARA
- JSpOC

GPM Mission Debris Avoidance Maneuver Criteria

	Pc Thresholds	Odds Range	Course of Action	Caveats
Green	**< 1.0 × 10⁻⁵**	**1:100,000 to 0**	**No DAM**	
Yellow	**Between 1.0 × 10⁻⁵ and 1.0 × 10⁻⁴**	**1:10,000 to 1:100,000**	**DAM**	…unless the maneuver results in more than minimal impacts to operations or mission objectives…
Red	**Between 1.0 × 10⁻² and 1.0 × 10⁻⁴**	**1:10,000 to 1:100**	**DAM**	…unless the maneuver results in vehicle hardware damage, or other significant operational impacts that increase the overall risk to the current or future mission
Black	**≥1.0 × 10⁻²**	**1:100 to 1:1**	**DAM/EDAM**	None

GPM DAM History

ID	Object	Days	TCA(s)	Max P_C	ODDS	Action Taken
39063	H2A R/B	2.5	04/22/20140 1:57	4.58×10^{-4}	1 : 2,183	Requested assessment from CARA. High Interest Briefing held DAM #001 (DMUM #007) executed on 04/21/14
40140	FLOCK 1B-17	4	10/13/2014 08:30	7.60×10^{-4}	1 : 1,316	Requested assessment from CARA. High Interest Briefing held DAM #002 (DMUM #017) executed on 10/11/14
24115	Pegasus Debris	3	06/02/2015 23:08	6.57×10^{-4}	1 : 1,522	CARA Meetings led to altering of the scheduled DMUM on 06/03 DAM #003 (DMUM #029) executed on 06/02/15
41776	FLOCK 2E' 17	6.9	01/23/2017 13:23	9.00×10^{-5}	1 : 11k	GPM stood up DAM #04, sent to CARA for screening (TCA-2 days). At TCA-24h, Pc subsided to acceptable level. GPM executed DAM #004 (DMUM #043) executed on 01/28/17
25544	ISS (Zarya)	6.7	09/16/2017 23:58	2.13×10^{-3}	1 : 469	Coordinated with ISS/TOPO. CARA HIE Briefing and addition support DAM #005 (DMU #048) executed on 09/15/17
		6.8	09/17/2017 01:30	1.66×10^{-3}	1 : 602	
		6.8	09/17/2017 03:03	1.11×10^{-5}	1 : 90k	
		6.9	09/17/2017 04:35	8.53×10^{-7}	1 : 1.17M	
		6.5	09/17/2017 06:08	1.61×10^{-5}	1 : 62k	
31500	FENGYUN 1C Debris	1.5	12/07/2017 21:59	1.20×10^{-5}	1 : 83k	This Close Approach occurred after the CAM for Retro #004 was approved, hours before the burn. GPM WAIVED the maneuver and executed the Back-Up burn the next day, which mitigated the conjunction.
43498	ISS Debris	3	07/11/2018 14:07	$1.83\times10{-8}$	1 : 55M	68+ orbit repeating conjunction. Consulted with SpaceNav. Proposed 2 maneuvers, CARA Screened. DAM #006 (DMUM #053) executed on 07/09/18
		3	07/11/2018 15:40	$5.24\times10{-5}$	1 : 19k	
		3	07/11/2018 17:12	$9.70\times10{-8}$	1 : 10M	
		3	07/12/2018 05:33	3.86×10^{-9}	1 : 259M	
		3	07/12/2018 07:05	5.91×10^{-10}	1 : 1.6B	
		3	07/12/2018 08:38	1.36×10^{-7}	1 : 7.3M	
		3	07/12/2018 10:10	1.25×10^{-7}	1 : 8.0M	
		3	07/12/2018 11:43	6.87×10^{-8}	1 : 14.6M	

Relative Motion In-Plane (LVS-XZ) Plot

ISS Orbital Velocity

Keep Out Volume

Relative Motion example of a CubeSat deployed from ISS over 8 days

Deployment Zone

Earth
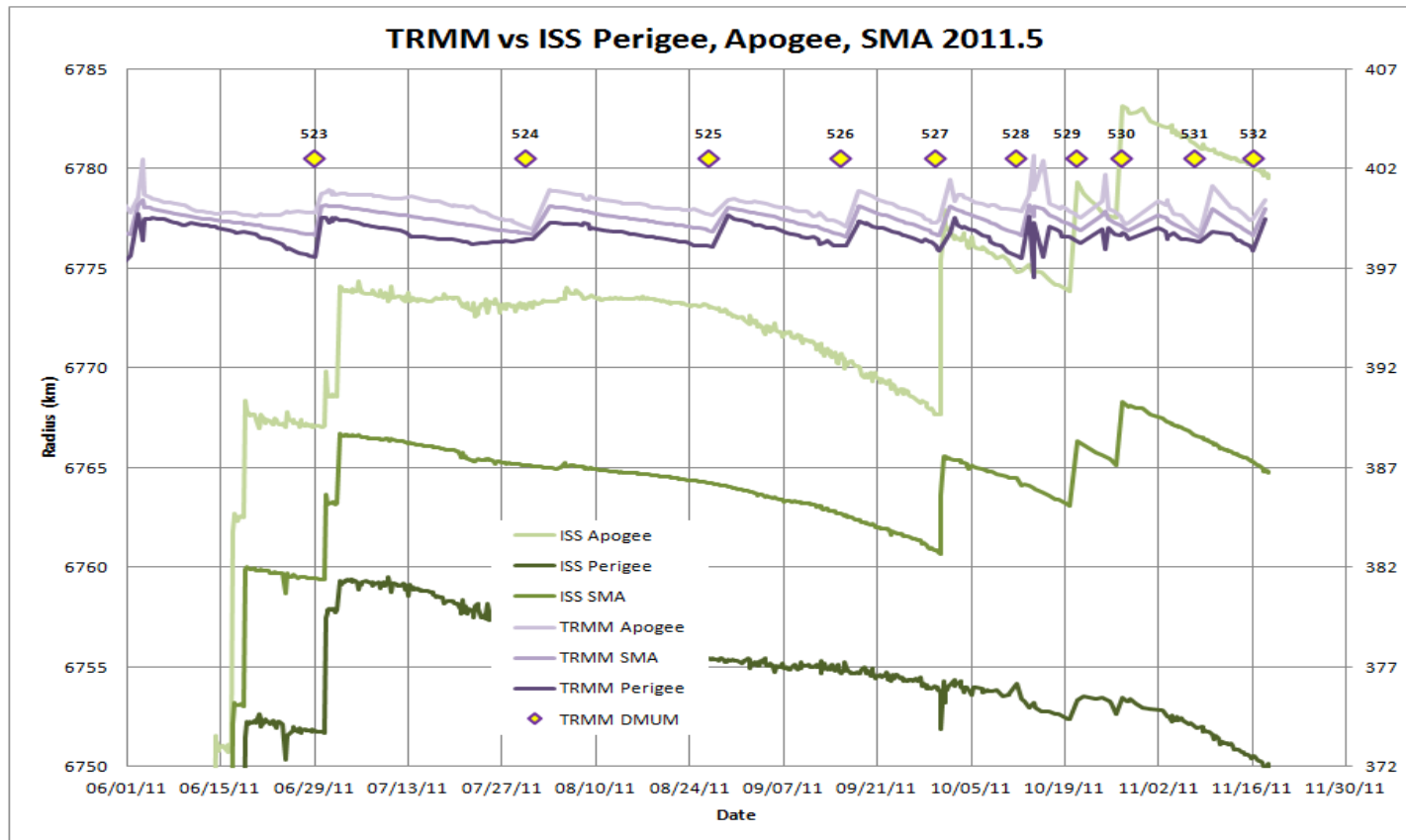
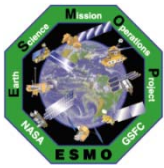Z-LVS (km)

X-LVS (km)
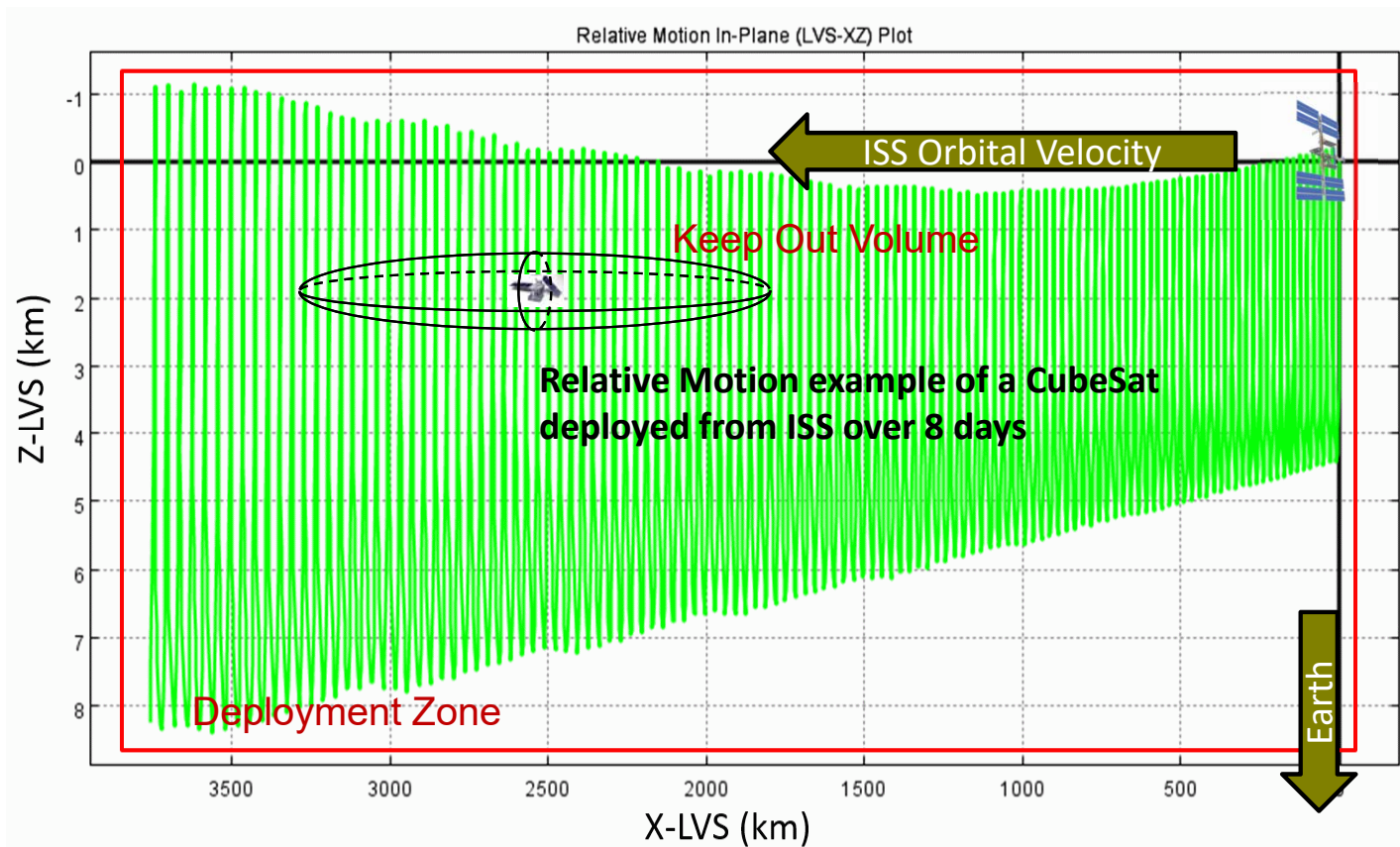
TRMM v ISS Study

- Based on recent CARA issues with regard to TRMM and ISS, the following analysis was developed to study previous possible close approaches missed with the current (old) screening process.
- Previous screening process could have missed close approaches where there was a burn by ISS and TRMM within a day of each other.
- FDS analysts used Space-Track.org TLEs for both ISS and TRMM as the data set from 2005 to present.
- TLEs were used to generate Perigee, Apogee and Semi Major Axis (SMA) for both vehicles on the same plot.
- Results showed there was no concern prior to June of 2011, when shuttle missions to the ISS ceased.
- ISS dramatically increased it's orbit in June 2011 from ~340 km SMA to ~390km SMA, however, the Apogee did not cross TRMM's Perigee until September 30TH, 2011.
- During this period, TRMM performed four (4) DMUMs
    - DMUM #527, September 29, 2011   Possible Conjunction/Not Screened
    - DMUM #528, October 11, 2011   Possible Conjunction/Not Screened
    - DMUM #529, October 20, 2011   Problem Identified
    - DMUM #530, October 27, 2011   Manually Screened
    - **DMUM #531, November 7, 2011   Manually Screened**
    - **DMUM #532, November 16, 2011   Manually/Auto Screened**
    - **DMUM #533, November 22, 2011   Manually/Auto Screened**
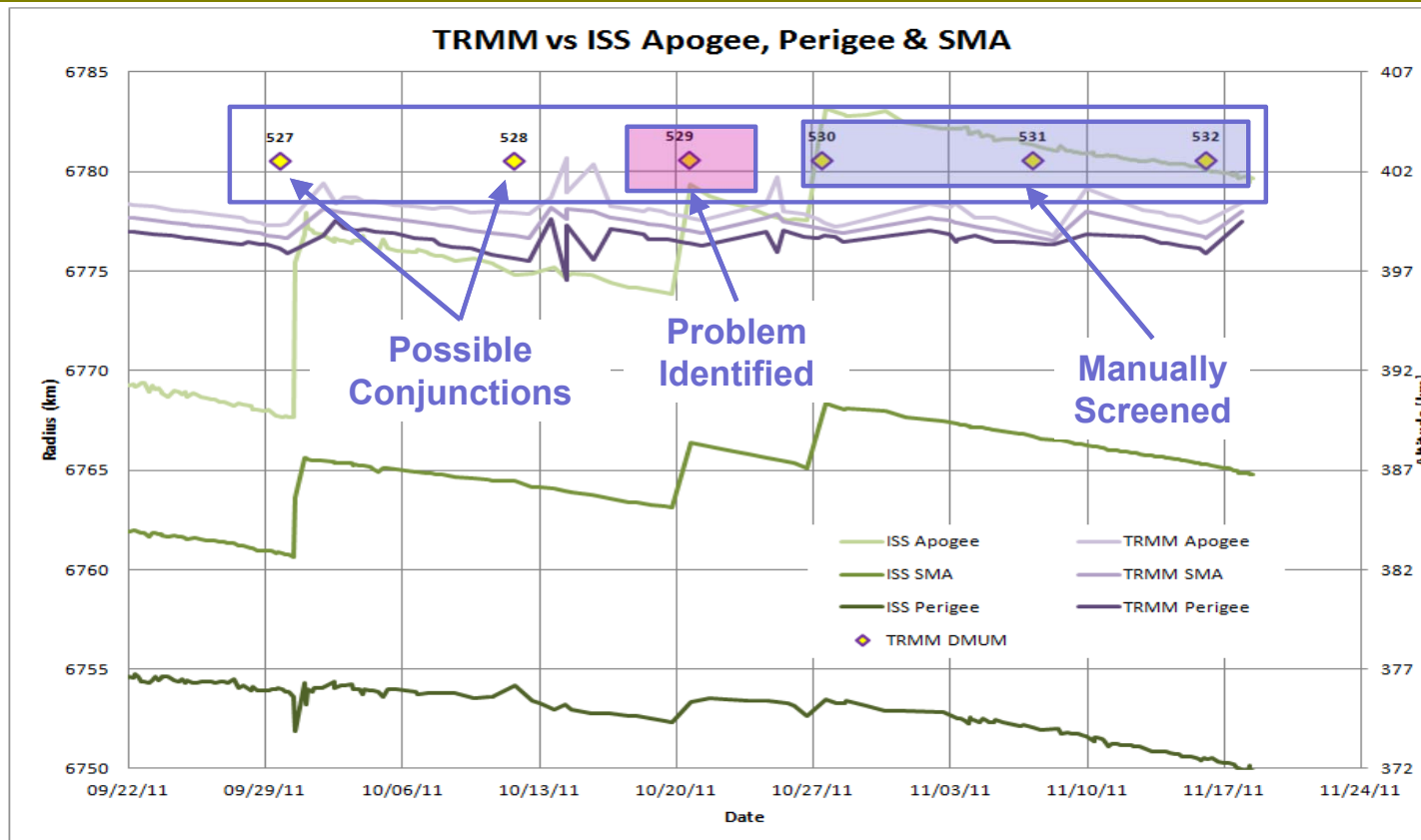   - **DMUM #534, November 30, 2011   Manually/Auto Screened**

TRMM vs ISS Perigee, Apogee, SMA 2011.5
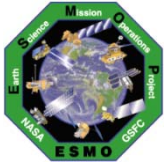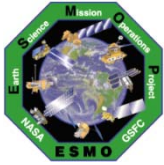
TRMM & ISS Orbital History
DMUM's #526, #527, #528, #529, #530

Acronyms

CA	Conjunction Assessment	HIE	High Interest Event
CAM	Command Authorization Meeting	ISS	International Space Station
CARA	Conjunction Assessment Risk Analysis	JSpOC	Joint Space Operations Center
DAM	Debris Avoidance Maneuver	KOV	Keep-out Volume
DMU	Drag Make Up	MTS	Maneuver Trade Space
DMUM	Drag Make Up Maneuver	NASA	National Aeronautics and Space Administration
DZ	Deployment Zone	OA	Operations Agreement
EDAM	Emergency Debris Avoidance Maneuver	Pc	Probability of Collision
ESMO	Earth Science Mission Operations	SMA	Semi-Major Axis
FDS	Flight Dynamics System	TCA	Time of Closest Approach
FOT	Flight Operation Team	TOPO	Trajectory Operations and Planning Officer
GPM	Global Precipitation Measurement	TRMM	Tropical Rain Measurement Mission
GSFC	Goddard Space Flight Center		